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Map design for visually impaired people: past, present, and future research

Anke M. Brock, Bernard Oriola, Philippe Truillet, Christophe Jouffrais*, and Delphine Picard*

*both authors contributed equally to the study

Anke Brock is a Ph.D. student. Her Ph.D. is supervised by D. Picard, C. Jouffrais and P. Truillet. The defense is planned for 2013. In 2012 she received a Google Anita Borg Scholarship. She teaches Human-Computer Interaction (HCI) and programming at the University of Toulouse. Her research on interactive maps for visually impaired people can be found at http://www.irit.fr/~Anke.Brock; Email: anke.brock@irit.fr

Bernard Oriola is a CNRS research engineer at the IRIT Research Institute for Computer Science (UMR 5505, joint laboratory between the University of Toulouse and the CNRS - National Center for Scientific Research). His research interests consist of HCI and particularly non-visual interaction. His recent work focuses on assistive technologies for the blind. His publications can be found at http://www.irit.fr/publications.php3?code=235&nom=Oriola Bernard; E-mail: Bernard.oriola@irit.fr

Philippe Truillet is an associate professor at the University of Toulouse. He teaches Human-Computer Interaction, networks, programming and works at the IRIT Research Institute for Computer Science. His publications can be found at http://www.irit.fr/~Philippe.Truillet; E-mail: Philippe.Truillet@irit.fr

Christophe Jouffrais is a CNRS researcher at the IRIT. His research interests included the neural mechanisms of visually-guided behavior and 3D perception and more recently space perception and oriented behaviors in visually impaired (VI) people, as well as assistive technologies for VI people. His publications can be found at http://www.irit.fr/~Christophe.Jouffrais; Email: christophe.jouffrais@irit.fr

Delphine Picard is a full professor at Aix Marseille University, and member of the French University Institute. She teaches psychology, and works at the Research Center in the Psychology of Cognition, Language and Emotion (Centre PsyClé, EA3273). Her publications on haptic perception in blind and sighted subjects can be found at http://www.dpicard.fr; E-mail: delphine.picard@univ-amu.fr

Résumé

L’orientation et la mobilité font partie des défis les plus importants pour les déficients visuels. Jusqu’alors, les cartes papier en relief ont été utilisées pour rendre accessibles les informations géographiques. Mais ces cartes présentent des limitations significatives en ce qui concerne leur contenu et la présentation des informations. Les avances technologiques aident à créer des cartes interactives permettant de surmonter de telles limitations. Dans cet article, nous procédons tout d’abord à une revue de la littérature sur les différentes cartes accessibles pour déficients visuels. Nous présentons ensuite les étapes de la création d’une carte interactive, en apportant la preuve expérimentale d’une grande satisfaction d’usage pour cette carte interactive comparée à une carte papier classique en relief. Pour conclure, nous suggérons que les avancées dans les technologies interactives fournissent une opportunité unique pour le design de cartes accessibles dans un futur proche.

Mots Clés: Cartes Interactives; Interaction Homme-Machine; Accessibilité; Design de cartes; Déficience visuelle; Technologies interactives; Multi-touch

Abstract

Orientation and mobility are amongst the most important challenges for visually impaired people. Tactile maps can provide them with spatial knowledge of their environment, thereby reducing fear related to travelling in space. To date, raised-line paper maps have been used to make geographic information accessible, but these paper maps have significant limitations with regards to content and the presentation of information. Recent advances in technology may help to design usable interactive maps that overcome such limitations. In this paper, we first review different accessible map concepts. We then present our design of an interactive map prototype, and provide evidence of this interactive map's high user satisfaction and efficiency as compared to a regular raised-line paper map. To conclude, we suggest that advances in interactive technologies (e.g., haptic touch surfaces) provide a unique opportunity to design usable maps in the near future.

Keywords: Interactive Maps; HCI; Accessibility; Map design; Visual Impairment; Multi-touch

Introduction

Imagine moving to an unknown city. What would you do to obtain accurate knowledge of the environment? Read a map? Go out and explore the streets in your neighborhood? Both activities are easy to perform if you are sighted. However, for visually impaired (VI) people, orientation and mobility are challenging. Yet, different studies proved that VI people can achieve spatial cognition (Ungar, 2000). Mental mapping is usually performed through the integration of information perceived by the senses. When vision is lacking, spatial information perceived through external (auditory, olfactory, somatosensory) and internal (perception of own posture and movement) cues provides only a partial perception of space and events. Therefore, exploring an unknown environment is stressful and sometimes dangerous for VI people (Gaunet & Briffault, 2005). Mental mapping can be achieved more safely using indirect sources of information, such as verbal descriptions or tactile representations of an environment (maps or small-scale models) (Jacobson, 1996; Picard & Pry, 2009). The latter are miniaturized symbolic representations of a real space. Tactile maps allow for the absolute and relative localization of spatial objects such as streets or buildings, the estimation of distances and directions, as well as finding an itinerary between two points (Hatwell & Martinez-Sarrochi, 2003).

From paper to interactive maps

Tactile paper maps (also called raised-line maps) have long been used to present spatial information to VI people. They were used both as a learning device during education and as a wayfinding aid for navigation (Jacobson, 1996). Despite their common usage by VI people, these maps have important limitations. First, due to the specificities of the tactile sense, raised-line maps must be scanned sequentially, placing great demands on memory. Second, tactile maps include a large amount of information, often resulting in perceptual overload for readers (Jacobson, 1996). Third, the usage of Braille in tactile maps is critical. However, Braille text requires a lot of space, and does not adapt to changes in orientation, inter-cell spacing and font properties (Tatham, 1991). Many VI people do not read Braille: in France, only 15% of the Blind are Braille readers (C2RP, 2005). Using a separate legend in Braille potentially introduces interpretation problems as referencing is disrupted during map reading (Jacobson, 1996). Last, once maps are printed on swell paper, the information they contain cannot be modified or updated and can therefore become quickly invalid (Yatani, Banovic, & Truong, 2012).

The introduction of new technologies in recent years has opened up possibilities for designing accessible maps. As argued by Oviatt (1997), maps that are based on the use of interactive technology have the potential to provide a substantially broader spectrum of the population with spatial knowledge, irrespective of age, sensory impairment, skill level, or other considerations. Looking at the literature concerning existing concepts of accessible interactive maps has indicated that several research projects have been devoted to the design of interactive maps for VI people within the 25 last years (from 1988 to today). All of these projects involved interactive geographic maps (including mostly streets and buildings). Within this corpus, the underlying concepts for map designing differ in various noticeable aspects. In Table 1, we propose a classification of 25 map prototypes, based on the following three criteria: 1) type of input and output modalities (regarding to the device, not the user), 2) number of modalities used (unimodal versus multimodal), 3) the possibility to use the device in mobility (immobile versus mobile).

Table 1. A classification of interactive map projects

			OUTPUT						
			Unimodal	Multimodal					
INPUT			Auditory feedback	Audio + haptic device	Audio + display with pins	Audio + raised-line map	Audio + haptic mouse + raised-line map	Audio + tactile reference frame	Audio + vibration
Immobile	Unimodal	Touch screen or sensor	Heuten *et al.* 2006; Jacobson 1998; Kane *et al.* 2011		Shimada *et al.* 2010; Zeng *et al.* 2010	Brock *et al.* 2012; Miele *et al.* 2006; Minatani *et al.* 2010; Paladugu *et al.* 2010; Parkes 1988; Wang *et al.* 2009			
Immobile	Unimodal	Touch through image recognition				Seisenbacher *et al.* 2005			
Immobile	Unimodal	Mouse or haptic device		Kaklanis *et al.* 2011; Rice *et al.* 2005					
Immobile	Unimodal	Keyboard	Zhao *et al.* 2008						
Immobile	Unimodal	Tangible						Pielot *et al.* 2007	
Immobile	Unimodal	Gamepad							Schmitz *et al.* 2010
Immobile	Unimodal	Generic haptic input device		Parente *et al.* 2003					
Immobile	Multimodal	Touch + keyboard				Weir *et al.* 2012			
Immobile	Multimodal	Touch + speech recognition	Kane *et al.* 2011						
Immobile	Multimodal	Touch + mouse					Campin *et al.* 2003		
Immobile	Multimodal	Haptic device, keybord + speech recognition		Simonnet *et al.* 2009					
Immobile	Multimodal	Tangible + body orientation	Milne *et al.* 2011						
Immobile	Multimodal	Generic + keyboard	Parente *et al.* 2003						
Mobile	Unimodal	Touch screen	Su *et al.* 2010						Poppinga *et al.* 2011; Yatani *et al.* 2012

Inspection of Table 1 shows that most interactive map prototypes in recent research are immobile and assist the preparation of itineraries at home, before travelling. Some of these devices involve unimodal input through touch sensitive screens, and unimodal auditory output, providing, for instance, the name of geographic elements or sounds when the user touches the screen (Heuten, Wichmann, & Boll, 2006; Jacobson, 1998; Kane *et al.*, 2011). Several map projects are based on a similar system, but with a raised-line paper map placed on top of the screen (Brock, Truillet *et al.*, 2012; Miele *et al.*, 2006; Minatani *et al.*, 2010; Paladugu *et al.*, 2010; Parkes, 1988; Wang *et al.*, 2009). The output is then multimodal as it is composed of tactile (the map's raised design) and auditory feedback. In certain dedicated devices, the raised-line map may be replaced by a field of actuated pins and input is perceived via a touch sensor integrated in the display (Shimada *et al.*, 2010; Zeng & Weber, 2010).

Finally, alternative input modalities exist, including image recognition (Seisenbacher *et al.*, 2005), haptic mice (Kaklanis *et al.*, 2011; Rice *et al.*, 2005), keyboards (Zhao *et al.*, 2008), tangibles (Pielot *et al.*, 2007) and gamepads (Schmitz & Ertl, 2010). Multimodal input devices are usually based on touch input in combination with other input techniques such as speech recognition (Kane *et al.*, 2011), keyboard input (Weir *et al.*, 2012) or a computer mouse (Campin *et al.*, 2003). Different approaches were proposed by Milne, Antle, & Riecke (2011) who used a pen and the body's orientation as input, as well as Simonnet *et al.* (2009) who combined usage of a haptic device with keyboard and speech input. In the BATS project (Parente & Bishop, 2003) a generic prototype was produced with the possibility to switch between several input devices, such as a mouse, a keyboard, a joystick, a touch pad or a gamepad, and to produce auditory output optionally combined with haptic feedback. Recently, mobile applications were designed. They are based on the use of mobile phones with audio output (Su *et al.*, 2010) or audio output combined with vibration (Poppinga *et al.*, 2011; Yatani *et al.*, 2012).

The different types of interactive maps summarized in Table 1 show both advantages and disadvantages. Zhao *et al.*(2008) demonstrated that navigating a map with a keyboard was more difficult for VI users than with a touch screen. Also, the recollection of objects in space improved when using a touch screen as compared to the same task with a computer mouse (Tan *et al.*, 2002). Given that most blind users have learned how to explore raised-line maps in school, using an interactive prototype based on a raised-line map relies on previously acquired skills and is thus probably easier to manage. Besides, tactile and audio modalities have complementary functions when presenting spatial information (Rice *et al.*, 2005). For example, Braille labels can be removed when using speech output. The map can then be designed without overcrowding, including essential (spatial) tactile information only. The audio information can also facilitate the recognition of tactile shapes (Golledge, Rice, & Jacobson, 2005). As a whole, these research projects show that the combined use of audio and tactile feedback is especially helpful when presenting geographic information. Hence, they argue in favor of the design of interactive devices made of raised-line maps placed over a touch-screen.

Design of our interactive map

In our own research projects, we developed an interactive map prototype that could be used as an experimental platform to study the usability of accessible maps and advanced non-visual interaction. We relied on a participatory design process adapted to VI users (Brock, Vinot, *et al.*, 2010) to ensure that users' needs were closely considered. In the following sections, we detail the different steps of the design process (analysis, creating ideas for the design, prototyping and evaluation) of the interactive map prototype.

1. **Analysis of the context of use**

A first step in the participatory design process was devoted to the analysis of the context of use (users' characteristics and users' tasks) as well as the technical environment (ISO - International Organization for Standardization, 2010). The context of use included aspects such as the characteristics and needs of blind users, the specificities of their spatial cognition, their inclination towards new technologies, and the influence of strategies during haptic exploration. The technical context included aspects such as the production of raised-line maps and the choice of hardware and software environments as described in Brock, Truillet, *et al.* (2010) and Brock, Truillet, *et al.* (2012). Both analyses allowed us to make choices regarding interaction techniques, map content and layout selected for our prototype in the next steps of the design process.

2. **Generating ideas**

Brainstorming is one of the standard methods used in participatory design for generating ideas. It is usually based on the extensive use of the visual sense (i.e. written notes on a blackboard), and is therefore not feasible with VI users. Nonetheless, it is possible to adapt brainstorming to VI people, with some remaining challenges (Brock, Vinot, *et al.*, 2010). We conducted several brainstorming sessions, with VI users and orientation and mobility instructors, which focused on the topic of mobility and orientation without sight. We specifically selected ideas that related to either the type of geographic information that would be dispensed (public transportation, tourist attractions, etc.) or the different levels of information accessible on a single map (for instance a first level on the name of the geographic element - i.e. "museum" -, and a second level on a set of practical information pertaining to the geographic element -i.e. opening hours-).

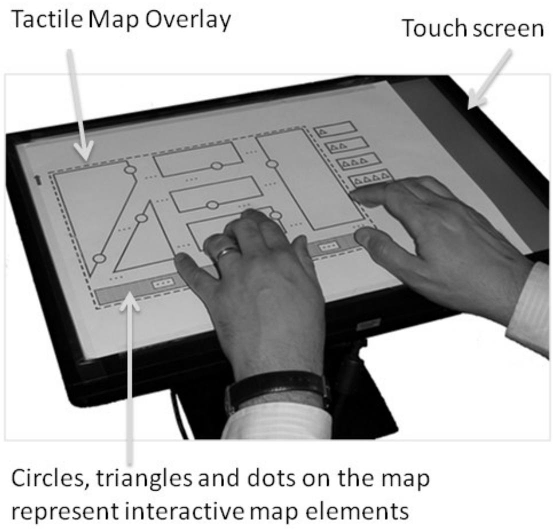

Figure 1. Photograph of our interactive map prototype

3. Prototype

Prototype design was based upon the previous analysis of context and generation of ideas. We developed successive versions of the prototype, taking into consideration users' needs and recommendations (see Brock, Truillet, *et al.*, 2012). The first prototyping step was a low-fidelity prototype based on the method of "Wizard of Oz". This method usually involves visual representations, but can be adapted to VI people (Brock, Vinot, *et al.*, 2010). Concretely, we adapted it by using raised-line maps and simulated speech output. Based on the pre-tests with the low-fidelity prototype, we confirmed the users' appreciation for the interactive map concept. The final prototype consisted of a raised-line map placed over a multi-touch screen (see Figure 1). Output interaction was both tactile (the map's raised design) and auditory (text-to-speech associated with touch events). We implemented a double tap as input interaction for a first version of the prototype. Details of the implementation and design are described in Brock, Truillet, *et al.* (2012).

4. Assessing prototype usability

Assessing the usability of any interactive device is central to participatory design. Usability is defined by three components, they are: efficiency, effectiveness and satisfaction (ISO - International Organization for Standardization, 2010). In a first study (Brock, Truillet, *et al.* 2012), we assessed user satisfaction for our prototype using a SUS questionnaire (Brooke, 1996). A high level of user satisfaction was obtained regardless of users' age, previous visual experience or Braille experience. Interestingly, our prototype made spatial information accessible to poor Braille readers who would have had serious difficulties with a classic raised-line map that included a Braille legend. In a second study (to be published), we compared satisfaction, efficiency (measured by exploration time) and effectiveness (measured by spatial learning) with our interactive map versus that of a classical raised-line paper map. Results indicated significantly higher efficiency and satisfaction with the interactive map than with the raised-line map, but showed no significant differences between the two types of maps in terms of spatial cognition (effectiveness). These findings allowed us to pursue the development of interactive maps for VI people with confidence.

5. Further development

Participatory design is an iterative process (ISO - International Organization for Standardization, 2010) and users' assessment of a prototype provides the keys to revising the design of the interactive map prototype in order to improve usability. One aspect worth considering relates to strategies used by blind users to read maps. Despite several studies in experimental psychology, the specific nature of these exploratory modes and their relations to performance level in spatial cognition remain obscure (Thinus-Blanc & Gaunet, 1997). Addressing these issues would be important for the design of accessible user interfaces. In this perspective, we developed Kintouch, a prototype that tracks finger movements by integrating data from the Microsoft Kinect camera and a multi-touch table (Brock, Lebaz, *et al.*, 2012). It registers the location of hands and digits during the exploration of a tactile map or image and can thus help analyzing haptic exploration strategies much more easily than with classical video observation. Our short-term objective is to use these observations in order to adapt interaction techniques and thus to make the prototype even more accessible and usable.

Conclusion

In this paper, we reviewed different concepts of accessible maps for VI people, starting with the classical raised-line paper maps and moving on to more recent interactive maps, including our own interactive map prototype. We have shown that new technologies can help overcome the limitations of traditional solutions. Touch screens and raised-line printers are nowadays relatively cheap, especially when compared to the specific equipment required by VI people. Therefore VI people could make use of interactive map prototypes in associations and schools, or even at home. However, as we have pointed it out, the development of interactive maps for VI people is a dynamic ongoing process, and the future will most likely offer blind users a variety of new and functional assistive technologies. Namely, in the near future, new touch screen technologies are likely to remarkably improve accessible map design. Several current projects aim to develop tactile devices with haptic feedback (see for example Bau & Poupyrev, 2012). Interestingly, such devices will promote the design of interactive maps, without the need to superimpose raised-line paper maps. Thus, the future of maps may even forego paper. The challenges would then be on advanced interaction that efficiently serves spatial cognition.

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